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METHOD FOR MANUFACTURING SEAMLESS STEEL TUBE
[Tsugimemu kokan no seizo hoho]

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[Claim(s)] /2*

[Claim 1] A method for manufacturing a high-strength, high-toughness seamless steel pipe outstanding in weldability characterized by containing, by % by weight, 0.02~0.15% of C, 0.1~1.5% of Si, 0.5~2% of Mn, 0.001~0.5% of solAl, 0~1.5% of Cr, 0~1.5% of Mo, 0~3.5% of Ni, 0~0.08% of Ti, 0~0.08% of Nb, 0~0.3% of V, 0~0.08% of Zr, 0~0.01% of Ca, 0~0.8% of Cu, and 0~0.008% of B, with the balance comprising Fe and inevitable impurities; applying a finish rolling at a finishing temperature of 800 to 1,050°C and a cross-sectional compressibility of at least 40% to steel, which has 0.05% or less P, 0.01% or less S, 0.01% or less N, and 0.01% or less O (oxygen), from among the inevitable impurities, in a hot rolling in which this steel is worked into a seamless steel pipe after a hot piercing, charging a heating furnace maintained in a temperature region of from 850 to 1,100°C with the seamless steel pipe as is, keeping it in the furnace for 3 seconds to 30 minutes, subsequently performing a direct quenching at an average cooling rate R (°C/sec) shown in the Expression (1) below between 800°C and 500°C, and then tempering it at the temperature T (°C) shown in Expression (2) or (3) below depending on the thickness of the steel pipe.

(When t (mm) is defined as the thickness of the seamless steel pipe, then

$$R \geq (10^{[illegible]})/(t^{1.4}) \cdots\cdots\cdots (1)$$

* Claim and paragraph numbers correspond to those in the foreign text.

When T is defined as the tempering temperature (°C), then:

$$500-2.3\times t \leqq T \leqq 720-1.1\times t \cdots [illegible]$$

and when 30≤t, then:

normal temperature $\leqq T \leqq 720-1.1\times t \cdots$ [illegible]

[Detailed Specifications]

[0001]

[Technical Field of the Invention] The present invention relates to a seamless steel pipe having high strength and high toughness, is outstanding in weldability, and is used for probing for, collecting or transferring crude oil or natural gas, and in particular, a method for manufacturing the seamless steel pipe used as a line pipe.

[0002]

[Prior Art] A direct quenching method has been adopted in many plants as a method for heat treating a seamless steel pipe. However, even if a steel pipe having a high carbon equivalence can be provided with high strength and high toughness without the need to consider welding, and consequently, high quenchability in a direct quenching method, at the present, it is difficult to simultaneously satisfy high strength and high toughness for a seamless steel pipe in which the carbon equivalence decreased in consideration of the weldability. Therefore, it was necessary to perform a normal quenching and tempering treatment on a seamless steel pipe for a line pipe, with emphasis on the weldability, by installing a quenching oven and a tempering oven separately from the manufacturing line. Here, the term

"direct quenching" means a method in which the steel is transferred from a rolling line as is after rolling to a quenching facility where it is quenched, or it is introduced into a facility, such as a heating furnace, attached to the rolling line as is after the rolling and subsequently transferred to a quenching facility where it is quenched. In addition, in the case of a nonsteel pipe or a steel pipe, the term "seamless steel pipe" will be used hereinafter.

[0003] In order to apply a direct quenching to a seamless steel pipe having a composition in which the carbon equivalence has decreased and to provide high strength and high toughness, the following three types of measures for improvement have been proposed thus far.

[0004] (a) In order to improve toughness, methods in which steel cooled on a rolling line and subjected to a temporary ferrite transformation is reheated and subjected to a reverse transformation, whereby a subtle granulation is planned (publications of Tokukai Nos. JP-A S56-3626, H4-21721, H5-255749 and H5-255750), and methods in which cooling and reheating are performed after a final finish-rolling (publications of Tokukai JP-A Nos. S58-91123 and S58-104120) are disclosed.

[0005] However, these methods require a facility which consume a lot of energy, is complex, and has high construction costs; hence, no merits for high equipment costs or operating costs are brought about.

[0006] (b) From the point of view of refining crystal grains, methods in which working was performed in an unrecrystallization temperature region, after which recrystallization was performed to obtain a refined recrystallized grains, and subsequently subjected to a finish rolling, direct quenching, and tempering are cited (publications of Tokukai JP-A Nos. H6-172854, H6-172855, H6-172857, H6-172858, H6-184635, H6-184636, and H6-184711). In these methods, a larger-than-normal working distortion is introduced in the unrecrystallization temperature region and after that it is subjected again to a hot rolling, whereby fine recrystallized grains are obtained by means of one or two oblique rolling machines having large shear distortion components.

[0007] However, since a large working distortion was introduced in these methods, a problem occurred more than usual because an oblique rolling generates many flaws during pipe production in a low-temperature region. Furthermore, since a final rolling was performed in the recrystallization temperature region, the reheating temperature had to be set to a high temperature, and refining according to an oblique rolling was not adequately made use of.

[0008] (c) In the publication of Tokukai JP-A No. S61-238917, after a pierced rolling, the heating conditions are severely limited, and a proposal was made to obtain a refined structure by recrystallizing at least 90% of the structure. However, the working

conditions for a seamless steel pipe are not wholly described; hence, it is unclear if this method can actually be carried out.

[0009] In general, when a direct quenching is applied to a steel pipe having a chemical composition with low quenchability, the following problems develop in addition to the above-mentioned problem.

[0010] (a) It is hard to obtain a homogeneous, quenched structure over the entire seamless steel pipe (quenching distortion). As a result, the mechanical properties are dispersed over the longitudinal direction of the steel pipe in particular.

[0011] (b) A seamless steel pipe is strongly influenced by a fluctuation in the thickness, and the mechanical properties are greatly degraded across a certain thickness when the pipe is thicker than that. The thickness limits fluctuate even when the composition is the same with manufacturing opportunity.

[0012] In the case of steel wherein the chemical composition, with the emphasis on weldability, e.g., the carbon equivalence or quenchability was reduced, the dispersion width becomes large in both (a) and (b) above.

[0013]

[Problems to be Solved by the Invention] An object of the present invention is to provide a method for manufacturing a seamless steel pipe by a direct quenching and a tempering that suppressed the dispersion of the mechanical properties, as it is a composition whose quenchability was lowered to satisfy the weldability.

[0014] The term "weldability is outstanding" herein means the fact that both the weld cracking sensitivity is low and the toughness of the welded parts is satisfactory. In addition, the term "the toughness of the welded part is satisfactory" means that the toughness is satisfactory in a case in which a heat-affected zone (HAZ) which is a position, at which the bond or the parent material side of the bond, with significance to the interface in which the welding metal and the base material touch, is placed 1 to 5 mm from either side thereof.

[0015]

[Means for Solving the Problems] The inventors of the present invention performed studies by placing an emphasis on the chemical composition, on the rolling method and a heating method just before a direct quenching, and on the quenching and cooling rate. As a result, they confirmed that satisfactory and uniform mechanical properties were obtained over the entire seamless steel pipe by performing a direct quenching by means of a suitable rolling using a suitable quenching apparatus after heating the entire steel tube using a specific heating device attached to a rolling line and conducting tempering according to specific conditions. An outline of this method is summarized as follows.

[0016] (A) Refining of crystal grains: After piercing, work at a cross-sectional compressibility of at least 40% is conducted in a finish rolling method in which both elongation and rolling are

performed integrally at 800 to 1,050°C. When a seamless steel pipe is introduced with a satisfactory work distortion by means of this work at 40% or greater, and it is kept in a furnace maintained at 850 to 1,100°C for 3 seconds to 30 minutes, recrystallization is accelerated, the crystal grains are refined, and the toughness is improved.

[0017] (B) Heating of the entire steel pipe just before direct quenching: The heating apparatus attached to the rolling line makes use of a heating furnace having a width at which the entire seamless steel pipe subjected to the above intensive working is heated evenly at one time. Thus, the dispersion of the mechanical properties over the entire steel pipe, and in particular, the gradient of the mechanical properties in the longitudinal direction is reduced remarkably.

[0018] (C) Cooling rate of direct quenching: The cooling rate for direct quenching is at least a constant cooling rate, depending on the thickness. In conjunction with this cooling rate and the effects for improving the characteristic quenchability in the direct quenching method, a seamless steel pipe can also be manufactured, with a margin, as a thick steel pipe having a composition with low quenchability and simultaneously having a relatively low thickness at a high productivity. Even if the thickness is low, a method in which a constant cooling rate is ensured will be described later.

[0019] (D) Tempering conditions: Figure 1 is a drawing expressing the influence of the tempering temperature on the yield

stress of the seamless steel pipe manufactured in the method of the present invention (0.07%C-0.22%Si-1.3%Mn-0.01%P-0.001%S-0.27%Cu-0.08%Ni-0.05%Cr-0.032%Nb-0.023%Ti-0.035%solAl-0.0013%Ca). According to this drawing, the yield strength of the thick seamless steel pipe is lower than that of a thin steel pipe tempered at a low temperature. But even if the tempering temperature rises, the reduction in the yield strength is slack; hence, in a range of 650 to 700°C, it is the same temperature as that of a thin steel pipe. Therefore, to manufacture a thin steel pipe from a thick steel pipe at the same strength level using the same steel by a direct quenching and a tempering, the tempering temperature is increased for a thin steel pipe and is decreased for a thick steel pipe. Thus, it is not necessary to prepare a few types of billets of varying compositions depending on the thickness, while a curtailment in distribution costs also is enabled at the same time.

[0020] The present invention was completed by combining steel having outstanding weldability and a method for working and heat treating the seamless steel pipe. The gist is a method for manufacturing a seamless steel pipe characterized by using the following composition and performing a hot rolling, a heat treatment just before a direct quenching, and then a direction quenching and a tempering.

[0021] A method for manufacturing a high-strength, high-toughness seamless steel pipe outstanding in weldability

characterized by containing, by % by weight, 0.02~0.15% of C, 0.1~1.5% of Si, 0.5~2% of Mn, 0.001~0.5% of solAl, 0~1.5% of Cr, 0~1.5% of Mo, 0~2.5% of Ni, 0~0.08% of Ti, 0~0.08% of Nb, 0~0.3% of V, 0~0.08% of Zr, 0~0.01% of Ca, 0~0.8% of Cu, and 0~0.008% of B, with the balance comprising Fe and inevitable impurities; applying a finish rolling at a finishing temperature of 800 to 1,050°C and a cross-sectional compressibility of at least 40% to steel, which has 0.05% or less P, 0.01% or less S, 0.01% or less N, and 0.01% or less O (oxygen), from among the inevitable impurities, in a hot rolling in which this steel is worked into a seamless steel pipe after a hot piercing, charging a heating furnace maintained in a temperature region of from 850 to 1,100°C with the seamless steel pipe as is, keeping it in the furnace for 3 seconds to 30 minutes, subsequently performing a direct quenching at an average cooling rate R (°C/sec) shown in the Expression (1) below between 800°C and 500°C, and then tempering it at the temperature T (°C) shown in Expression (2) or (3) below depending on the thickness of the steel pipe.

[0022] (When t (mm) is defined as the thickness of the seamless steel pipe, then:

$$R \geq (10^{[illegible]}) / (t^{[illegible]}) \quad \cdots\cdots (1)$$

When T is defined as the tempering temperature (°C) and the thickness t(mm) is 0<t<30, then:

$$500 - 3.3 \times t \leq T \leq 720 - 1.1 \times t \quad \cdots (2)$$

and when $30 \leq t$, then:

normal temperature $\leqq T \leqq 730 - 3.1 \times t$ ··· ⑥

The term "finish rolling" in the method of the present invention means a rolling in a range in which the rolling participates in the refining of the crystal grains directly, and as described later, includes both "elongation and rolling" and "a normal finish rolling" in the final stage of rolling. In addition, the term "finishing temperature" refers to the temperature immediately after the finish rolling. After the finish rolling, the term "charging the heating furnace as is" refers to charging a heating furnace with the seamless steel pipe "without cooling to room temperature temporarily" after the finish rolling. If it is not cooled temporarily to room temperature, descaling, strain correction, and the like may be performed.

[0023] In the method of the present invention, while charging the heating furnace with the seamless steel pipe, all of the parts of the seamless steel pipe are placed into the heating furnace and heated to a prescribed temperature.

[0024] The average cooling rate from 800°C to 500°C is a cooling rate at a position at the core thickness of the pipe. In addition, the finishing temperature in the hot rolling is a temperature at the core thickness in the same manner.

[0025] The "tempering temperature when the thickness is at least 30 mm is a normal temperature" means that tempering is not performed, i.e., a direct quenching is performed as is.

[0026]

[Embodiments of the Invention] 1. Chemical composition. First of all, the reasons for limiting the chemical composition in this method of manufacture will be stated. The composition is expressed as '% by weight' hereinafter.

[0027] (a) Essential elements

C: C is an element necessary for enhancing the quenchability and improving strength. If it is less than 0.02%, the quenchability is unsatisfactory and a high yield strength is not obtained. However, if it is over 0.15%, the weld cracking sensitivity is high. Hence, the amount is set to 0.02 to 0.15%.

[0028] Si: Although Si is an element which enhances the tempering softening resistance, the toughness of the welded parts is reduced if this element is in excess. To improve the tempering and softening resistance, 0.1% or more of it is necessary, but if it is over 1.5%, degradation of the toughness of the welded part is remarkable; hence, the amount is set to 0.1 to 1.5%.

[0029] Mn: Mn enhances the quenchability and a prescribed structure is obtained by a direct quenching. And it is added to ensure the strength and toughness. If the content thereof is less than 0.5%, the definitive effects are not obtained. Meanwhile, when

it is over 2%, the toughness deteriorates. Hence, the amount is set to 0.5 to 2%.

[0030] solAl (acid-soluble Al): solAl means the Al remaining in completely solidified steel in an amount over the amount of Al that reacted with oxygen during refining or solidification. The solAl is allowed to remain, as AlN, to fix the N put into a solid solution that is detrimental to the prevention of pinhole generation during or immediately after solidification and to the toughness. The Al acts sufficiently on deoxidizing the oxygen during refining, and a trace amount of oxygen is contained in solidified steel even if a majority of the oxygen is removed. If the amount of solAl is less than 0.001% after solidification is completed, microscopic pinholes cannot be prevented from being generated immediately after solidification. In addition, solidification of N that is detrimental to toughness is insufficient. On the other hand, if the amount of the solAl is over 0.5%, the toughness decreases. Hence, the amount is set to 0.001 to 0.5%.

[0031] (b) Optional elements

The following elements need not be added, but since they have the respective useful effects, by containing a suitable amount thereof, depending on the element, far superior performance may be provided.

[0032] Cr: Cr is an element that is useful for enhancing the quenchability. The minimum required quenchability is ensured by the

essential elements; hence, Cr need not be added, when it is applied to a thicker steel pipe, it is used to ensure the required quenchability. When it is added, assuming the Cr content is at least 0.02%, an effect for enhancing the quenching as well as the tempering and softening resistance is obtained; hence, it is favorable to set the amount thereof to at least 0.02%. However, if it is over 1.5%, the toughness of the welded parts decreases. Hence, the amount thereof is set to 1.5% or less.

[0033] Mo: Mo need not be added. However, when the quenchability and tempering and softening resistance is to be further enhanced in the case of a thick steel pipe, this element is used in addition to the essential elements. If the content thereof is less than 0.02%, these effects are not definitely obtained; hence, it is favorable to set it to at least 0.02%. However, if it is over 1.5%, degradation of the toughness of the welded parts is remarkable; hence, the amount is set to 1.5% or less.

[0034] Ni: Ni need not be added, but Ni has an effect for enhancing the toughness of the steel matrix (base) when it is put into a solid solution; hence, it may be used in a case when a far superior toughness is to be stably obtained. When it is added, assuming the content thereof is at least 0.05%, an effect for improving quenchability is obtained; hence, it is favorable to set the amount to at least 0.05%. However, if it is over 2.5%, a

corresponding improvement in toughness is not obtained; hence, the amount is set to 2.5% at most.

[0035] Ti: Ti need not be added, but Ti has an effect for improving toughness by forming a carbide in the steel and preventing coarsening of the structure in the welded parts; hence, it is added when a far superior toughness is to be ensured in the welded parts. When it is added, assuming the content thereof is at least 0.005%, it is also effective for refining of the base material and it enhances the toughness of the base material; hence, it is favorable to set it to at least 0.005%. However, if it is over 0.08%, the reduction in the toughness of the base material is marked; hence, it is set to at most 0.08%.

[0036] Nb: Nb need not be added, but Nb enlarges the unrecrystallization temperature region during rolling to a high temperature. If Nb is not contained, the crystal grains recrystallized and grown during rolling elongate as the working distortion builds up due to rolling if Nb is contained, and the crystal grains subjected to recrystallization during heating prior to the direction quenching become fine, which is effective for improving toughness. When this element is added, assuming the content thereof is 0.005% or more, an additional effect for enhancing the tempering and softening resistance is obtained by a secondary deposition of NbC during tempering; hence, it is favorable to set the content thereof to at least 0.005%. However, if it is over 0.08%, the toughness of

the welded parts markedly deteriorates; hence, it is set to at most 0.08%.

[0037] V: V need not be added, but V is deposited during tempering after the direct quenching to enhance the tempering and softening resistance; hence, it is used when the yield strength is to be enhanced further. When it is added, assuming the content thereof is set to 0.01% or more, an effect for improving the tempering and softening resistance as well as the quenchability is also obtained; hence, it is favorable to set the amount to 0.01% or more. However, if it is over 0.3%, the toughness greatly deteriorates; hence, it is set to at most 0.3%.

[0038] Zr: Zr need not be added, but Zr produces a stable carbonitride even at high temperatures, and suppresses the crystal grain growth during heating of steel (billet) before piercing; hence, it is used when the crystal grains are to be further refined and the toughness is to be further improved. When it is used, assuming the content is 0.005% or more, it is effective for improving the toughness of the welded parts as well; hence, it is favorable to set it to at least 0.005%. However, if it is over 0.08%, the reduction in the toughness of the base material is marked; hence, it is set to at most 0.08%.

[0039] Ca: Ca need not be added, but Ca reacts with the S in the steel to produce a sulfocarbide in the molten steel. This sulfocarbide differs from MnS and the like in that it does not extend

in the direction of rolling by a rolling and it is spherical after rolling. Thus, it suppresses weld cracking or hydrogen-induced cracking (HIC), with the tip or the like of the elongated inclusion as the starting point; hence, it is used when suppressing weld cracking or HIC cracking.

[0040] When it is used, assuming the content is set to 0.0002% or more, there is also an effect for improving the toughness of the welded parts; hence, it is favorable to set it to at least 0.0002%. However, if it is over 0.01%, the toughness of the base material decreases and multiple flaws are generated in the surface of the steel pipe at the same time; hence, it is set to at most 0.01%.

[0041] Cu: Cu need not be added, but Cu is effective for raising the strength and improving the corrosion resistance; hence, it is used when an even higher yield strength and higher corrosion resistance are required. When it is used, assuming the content is set to 0.05% or more, the quenchability is also enhanced for the direct quenching; hence, it is favorable to set it to at least 0.05%. However, if it is over 0.8%, the hot workability decreases; hence, it is set to at most 0.8%.

[0042] B: B need not be added, but a trace amount of B remarkably enhances the quenchability during the direct quenching; hence, from the point of view of the corrosion resistance and toughness, it is used when the quenchability of a thick steel pipe is to be enhanced, or to compensate for reduced quenchability when Mn

and the like of the essential elements wane. When it is used, assuming it is set to 0.0002% or more, an effect for forming BN at the welded parts and fixing the N put into solid solution which is detrimental to toughness, as BN, is obtained; hence, it is favorable to set it to at least 0.0002%. However, if it is over 0.008%, the toughness of the base material and the welded parts are impaired; hence, it is set to at most 0.008%.

[0043] (c) Inevitable impurities

The following elements are some impurities that are mixed inevitably. In the case of the "inevitable impurities," a sufficient and satisfactory performance is not obtained if they are not controlled to the following ranges.

[0044] P: P is inevitably present in steel as an impurity. If the content is over 0.05%, it segregates into a grain boundary and the toughness declines; hence, it is defined as at most 0.05%.

[0045] S: S also contaminates steel as an impurity as with P. If the content is defined to over 0.01%, a coarse sulfide, such as MnS, is produced, which is elongated by a hot rolling, and the HIC resistance and toughness are reduced; hence, it is defined as at most 0.01%.

[0046] N: N is present in steel as an impurity, and in particular, it degrades the toughness of the welded parts; hence, the content is defined as at most 0.01%.

[0047] O (oxygen): O is present in steel as an impurity, which degrades malleability and toughness and generates surface flaws; hence, it is defined as 0.01% at most.

[0048] 2. Manufacturing conditions

The reason for setting the manufacturing conditions for the steel having the chemical composition below, with an emphasis placed on the above-mentioned weldability, will be explained.

[0049] (a) Heating and piercing steel: The steel charged into the heating furnace is one obtained by blooming it into a round rod shape or one manufactured by continuously casting it into a round template, and so forth. It may be any type as long as it is a so-called billet. In order to economize on energy, the billet may be charged into the heating furnace before it is completely cooled as far as room temperature after the blooming or continuous casting.

[0050] The heating temperature of the billet should be one in which this billet can be hot worked by a drilling machine. The optimum temperature varies by material and is determined by considering the high-temperature malleability and high-temperature deformation resistance. Normally it is favorable to heat it in a range of 1,100 to 1,300°C. In order to realize a highly efficient billet heating, the billet length is the integral multiple of a prescribed length. It is favorable to cut it to a prescribed length with a cutting machine installed in the final step of the heating

furnace before performing piercing after heating (first part of drilling machine).

[0051] In piercing, a hollow pipe stock (hollow shell) is manufactured by forming a through-hole in a solid billet when it is hot. The piercing method includes an oblique rolling, press piercing, and the like, but it is not particularly limited thereto. Moreover, since flaws are easily generated during piercing if the surface temperature of the billet decreases, an auxiliary heating device, such as an inductive heating device, may be installed.

[0052] (b) Elongation and rolling and finish rolling: The pierced hollow pipe stock is elongated by an elongation rolling and finish rolling, and the dimensions are adjusted to manufacture a seamless steel pipe with the desired shape. The work is done in a relatively low-temperature range as compared to working using a drilling machine. If the finish rolling is performed before the working distortion applied by a rolling is recovered, the working distortion in the elongation working is included as a substantial working distortion with a finish rolling, and can be utilized in refining of the structure by the work. In the present specifications, the term "cross-sectional compressibility in a finish rolling" means a "cross-sectional compressibility for combining the work for both the elongation and the finish rolling" after the piercing. In addition, the "cross-sectional compressibility" means the ratio (pipe

cross section before working minus the pipe cross section after working divided by the pipe cross section before working).

[0053] It is necessary to perform the above-mentioned "finish rolling" at a finishing temperature ranging from 800 to 1,050°C at a cross-sectional compressibility of 40% or more in the present invention. If the cross-sectional compressibility is less than 40%, a fine enough crystal grain is not obtained. The upper limit of the cross-sectional compressibility is not limited in particular because it varies depending on the material and the mill capability of the pipe to be manufactured. But since flaws are easily generated in the surface of the cross-sectional compressibility is over 80%, it is favorable that the cross-sectional compressibility not be over about 80%. If the finish rolling temperature is over 1,050°C, the crystal grains coarsen and a fine crystal structure is not obtained; hence, it is set to 1,050 or less.

[0054] Meanwhile, the lower the finish rolling temperature, the finer the recrystallized grains are. But if the finishing temperature is less than 800°C, the deformation resistance of the pipe stock is high and it is difficult to conduct working at a cross-sectional compressibility of 40% or more; hence, it is set to 800°C or higher.

[0055] In order to perform the finish rolling before the working distortion applied in the elongation is recovered after the piercing, the elongation and rolling machine and the finish rolling machine that were arranged apart and separately in the past now should be

arranged continuously and integrally. Due to the continuous integration, the cross-sectional compressibility for the finish rolling of seamless steel pipes of all sizes can be substantially set to 40% or more.

[0056] The tail end of the mandrel bar, which is an inner surface restricting tool, of the mandrel mill used for the elongation and rolling machine is hampered after the elongation and rolling are finished, whereby the mandrel bar should be one which can be used reciprocally by restoring the mandrel bar to the inlet side of the mill. In particular, it is preferably a mill wherein the speed at which the mandrel bar is restored is independent of the moving speed of the hollow pipe stock during elongation and rolling.

[0057] The size of the finish rolling machine should be one that does not include the inner surface restricting tool. In particular, it is favorable to use a so-called extracting size not provided with a function for extracting or separating the mandrel bar from the pipe rolled by a mandrel mill.

[0058] (c) Heat treatment: After the finish rolling, performing the heat treatment to advance recrystallization after the finish rolling but before the direct quenching is a major feature of the present invention. During heating, recrystallization is evoked and the crystal grains are refined. The heating method differs between a conventional coarse rolling and a finish rolling. Rolling is not performed after heating in the method of the present invention; hence,

the heating temperature can be set to the lowest temperature at which recrystallization advances. Thus, an exceedingly fine recrystallized grain is obtained.

[0059] If the heating temperature is less than 850°C in the case of the target low-carbon, low-alloy steel in the method of the present invention, with an emphasis on the weldability, a long time is required for recrystallization to finish, and the production efficiency decreases.

[0060] Meanwhile, if it is over 1,100°C, the crystal grains coarsen markedly; hence, the heating temperature is set to 850 to 1,100°C.

[0061] During this heating, all the parts of the seamless steel pipe are introduced into the heat treatment furnace maintained at the above-mentioned temperature, and all the parts should stay in the furnace simultaneously for 3 seconds to 30 minutes. If the time they are kept in the furnace is less than 3 seconds, recrystallization does not sufficiently advance, and if it is over 30 minutes, the completely recrystallized grains grow and coarsen; hence, the time kept in the furnace is set to 3 seconds to 30 minutes. All of the parts of the seamless steel pipe are introduced into the furnace at one time and kept there for 3 seconds to 30 minutes to correct dispersion in the temperature before the direct quenching, and in particular, improve the uniformity of the temperature in the longitudinal direction of the steel pipe.

[0062] With such a heating, the uniformity of the temperature in the longitudinal direction (rolling direction) of the seamless steel pipe can be improved and a dispersion in the quenching temperature on each occasion of rolling can be suppressed.

[0063] (d) Direct quenching and tempering treatments: In the method of the present invention, the steel pipe is heated as is to 850 to 1,100°C; hence, even if the temperature of parts of the steel pipe drops after the rolling to lower than the Ar_3 point and ferrite is produced, all of the parts of the steel tube introduced into the heating furnace are made austenite again. Thus, the steel pipe having a homogeneous performance is stably supplied easily in an actual operation.

[0064] In the case of a chemical composition having a low quenchability, with emphasis on the weldability, a quenched structure composed mainly of ferrite is obtained by the usual quenching treatment, and a satisfactory quenched structure in which martensite and a fine beinite are mixed is not obtained. Although the quenchability is improved in a direct quenching method as compared to the usual quenching method, the cooling rate R should be set to a cooling rate in the range of the Expression (1) below to obtain a stable and satisfactory quenched structure by applying a direct quenching to the steel having a chemical composition with low quenchability, with emphasis on the weldability.

[0065]

$$R \geq 10^{3.1}/t^{1.4} \quad \cdots (1)$$

(Provided R is the average cooling rate (°C/sec) from 800°C to 500°C and t (mm) is the thickness of the steel pipe.)

[0066] To set such a cooling rate, merely immersing the seamless steel pipe in a water tank is insufficient. The cooling rate satisfying the Expression (1) can be effected, for example, by allowing a high-pressure jet water current to flow on the inner side while rotating the steel pipe, arranging multiple nozzles in the longitudinal direction of the steel pipe on the outer surface and allowing a laminar water current flow.

[0067] When the thickness is less than 30 mm, the structure obtained by the direct quenching is tempered at a temperature at the Ac_1 point or less to obtain moderate strength and toughness. The tempering temperature is dependent on the thickness t (mm) of the steel pipe and tempering is done at the temperature T (°C) shown in Expression (2) below.

[0068]

$$500-2.5\times t \leq T \leq 720-1.1\times t \quad \cdots (2)$$

When the thickness is 30 mm or greater, tempering is done at a tempering temperature satisfying Expression (3) below even when tempering is not performed with an emphasis on ensuring strength.

[0069]

$$\text{Normal temperature} \leq T \leq 720-1.1\times t \quad \cdots (3)$$

When the thickness is less than 30 mm, the lower limit of the tempering temperature in Expression (2) is such that if the temperature is lower than that and if the temperature is too high, the toughness is insufficient. Moreover, the upper limit of the tempering temperature is such that if tempering is done at a temperature over that, it is difficult to ensure the strength.

[0070] The tempering temperature is set to normal temperature or higher when the thickness is 30 mm or more, that is, direct quenching is done as is because a direct quenching is required as is to ensure the strength. In addition, if the temperature is over the upper limit shown by Expression (3), it is difficult to ensure the strength.

[0071]

[Practical Examples] Table 1 is a table expressing the chemical compositions of the steel used to put the present invention to practice and the steel of the comparative examples. In addition, Table 2 is a table expressing P, S, N and O (oxygen), from out of the inevitable impurities, of these steels. These steels were worked into round billets via the usual ingot-making and blooming in a 70-ton converter.

[0072]

[Table 1]

(wt%)

	c) Steel	C	Si	Mn	Cr	Ni	Mo	Cu	Ti	Nb	V	Zr	sol.Al	B	Ca
a)	A	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	—	[illegible]	—	—
	B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	[illegible]	—	—
	C	[illegible]	[illegible]	[illegible]	—	—	—	—	[illegible]	[illegible]	—	—	[illegible]	—	[illegible]
	D	[illegible]	[illegible]	[illegible]	—	—	[illegible]	—	—	—	—	—	[illegible]	—	—
	E	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	—	—	—	—	[illegible]	[illegible]	—	—
	F	[illegible]	[illegible]	[illegible]	—	—	—	—	[illegible]	—	[illegible]	—	[illegible]	—	[illegible]
	G	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	[illegible]	—	—
	H	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	—
	I	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	—	[illegible]	—	—
b)	Q	*[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	—	[illegible]	—	—
	R	[illegible]	[illegible]	[illegible]	—	*[illegible]	—	—	—	—	—	—	[illegible]	—	—
	S	[illegible]	[illegible]	[illegible]	*[illegible]	—	[illegible]	—	—	[illegible]	—	[illegible]	[illegible]	[illegible]	—
	T	[illegible]	[illegible]	[illegible]	[illegible]	—	*[illegible]	—	—	—	—	—	[illegible]	—	—
	U	[illegible]	[illegible]	[illegible]	—	[illegible]	—	*[illegible]	—	—	—	—	[illegible]	—	[illegible]
	V	[illegible]	[illegible]	[illegible]	—	[illegible]	—	*[illegible]	*[illegible]	—	*[illegible]	—	[illegible]	[illegible]	[illegible]
	W	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	—	[illegible]	*[illegible]	—	—	[illegible]	—	—

Key: a)Examples of the present invention; b)Comparative examples; c)Steel

A numerical value with * shows that it is outside the range of the present invention.

[0073]

[Table 2]

Table 2

(wt%)

	c) Steel	[illegible]	S	N	O
a)	A	[illegible]	[illegible]	[illegible]	[illegible]
a)	B	[illegible]	[illegible]	[illegible]	[illegible]
a)	C	[illegible]	[illegible]	[illegible]	[illegible]
a)	D	[illegible]	[illegible]	[illegible]	[illegible]
a)	E	[illegible]	[illegible]	[illegible]	[illegible]
a)	F	[illegible]	[illegible]	[illegible]	[illegible]
a)	G	[illegible]	[illegible]	[illegible]	[illegible]
a)	H	[illegible]	[illegible]	[illegible]	[illegible]
a)	I	[illegible]	[illegible]	[illegible]	[illegible]
b)	Q	[illegible]	[illegible]	[illegible]	[illegible]
b)	R	[illegible]	[illegible]	[illegible]	[illegible]
b)	S	[illegible]	[illegible]	[illegible]	[illegible]
b)	T	[illegible]	[illegible]	[illegible]	[illegible]
b)	U	[illegible]	[illegible]	[illegible]	[illegible]
b)	V	[illegible]	[illegible]	[illegible]	[illegible]
b)	W	[illegible]	[illegible]	[illegible]	[illegible]

Key: a)Examples of the present invention; b)Comparative examples; c)Steel

[0074] Table 3 is a table showing the conditions of the rolling and heat treatments performed on these round billets. This testing shows the test conditions for examining to what extent the dispersion in the yield strength is suppressed over the entire seamless steel pipe in the method of the present invention; numbers P1 to P4 are test pieces.

[0075] The degree of working, i.e., the "degree of piercing work" and the "degree of finish rolling work" in these tables indicate the surface area reduction ratio of the billet (solid) or the hollow pipe stock (hollow shell), that is, the cross-sectional compressibility. The finish rolling temperature is a calculated value obtained by assuming the temperature of the center part based on a measurement using a surface radiation thermometer. In addition, the

cooling rate in a direct quenching is a value found by performing an interpolation or an extrapolation from the cooling rate at the principal thickness measured thus far.

[0076]

[Table 3]

表 3

	番号	鋼	加熱温度 (℃)	穿孔の加工度 (%)	仕上げ圧延加工度 (%)	仕上がり温度 (℃)	加熱処理温度 (℃)	加熱在炉時間 (分)	肉厚 t (mm)	800-500℃平均冷却速度 (℃/秒)	K (℃/秒)	焼戻し温度 (℃)	L (℃)	M (℃)
本発明例	P1	A	1200	55	70	840	920	10	10	73	50.1	680	477.0	709.0
	P2	A	1200	50	45	930	920	10	40	14	7.2	540	—	876.0
比較例	P3	A	1200	55	70	840	* —	* —	10	73	50.1	660	477.0	709.0
	P4	A	1200	50	45	930	* —	* —	40	14	7.2	540	—	876.0

Key:

Table 3

	Number	Steel	Heating Temperature (°C)	Degree of Piercing Work (%)	Degree of Finish rolling Work (%)	Finishing Temperature (°C)
Examples of the Present Invention						
Comparative Examples						

[Table 3](cont.)

	Heat Treatment Temperature (°C)	Heating Time and Time Kept in Furnace (min)	Thickness t (mm)	800-500°C Average Cooling Rate (°C/min)	K (°C/sec)	Tempering Temperature (°C)		
Examples of Present Invention								
Comparative Examples								

-Column with the * shows that it deviates from the conditions of the method of the present invention.

- K=(0[illegible]/t)[illegible]: (°C/sec), L=500−2.3×t : (℃), M=720−1.1×t : (℃)

[0077] The test pieces P1 to P4 manufactured according to the manufacturing conditions in Table 3 are 12 m long seamless steel

pipes having a 178 mm diameter. The dispersion in the yield strength was examined at seven predetermined positions a, b, c, d, e, f and g from the ends of the pipes 2 m in the longitudinal direction of these steel pipes, and at four predetermined sites (1, 2, 3 and 4) at each of these positions at intervals of 90 degrees in the circumferential direction, and sampling the tensile test pieces in parallel to the axis of the pipe. That is, the yield strength was found at twenty-eight positions per steel pipe.

[0078] Here, K in the table represents $K=10^{3.4}/t^{1.4}$: (°C/sec; t is the thickness (mm)) which is the lower limit of the average cooling rate from 800 to 500°C in the present invention; L represents $500-2.3\times t$ (°C) which is the lower limit of the tempering temperature when the plate thickness is less than 30 mm in the present invention; and M represents $720-1.1\times t$ (°C) which is the upper limit of the tempering temperature.

[0079] Tables 4 to 6 are tables showing the conditions for manufacturing the test pieces for examining the improvement in the strength, toughness and weldability by applying the method of the present invention. Specifically, the tests mentioned next were performed.

[0080]

[Table 4]

表 4

	番号	鋼	加熱温度 (℃)	穿孔の加工度 (%)	仕上げ圧延加工度 (%)	仕上がり温度 (℃)	加熱処理温度 (℃)	加熱在炉時間 (分)	肉厚 t (mm)	800-500℃平均冷却速度 (℃/秒)	K (℃/秒)	焼戻し温度 (℃)	L (℃)	M (℃)
本発明例	1	A	1200	65	80	820	920	5	5	151	102.5	650	486.2	713.4
	2	A	1200	55	65	830	930	5	10	62	50.1	640	477.0	709.0
	3	A	1200	40	80	840	930	5	12	46	36.8	640	472.4	706.8
	4	A	1200	40	70	840	900	5	20	28	19.0	600	454.0	698.0
	5	A	1200	30	80	880	900	5	24	19	14.7	550	444.8	693.6
	6	A	1200	30	55	900	900	5	35	15	8.7	400	—	681.5
	7	A	1200	30	40	930	900	5	45	10	6.1	520	—	670.5
	8	B	1250	80	75	860	950	0.5	7	145	82.9	650	483.9	712.3
	9	B	1250	80	70	895	930	0.5	10	65	50.1	640	477.0	709.0
	10	B	1250	45	70	910	930	0.5	14	40	31.3	640	467.8	704.6
	11	B	1250	45	65	930	930	0.5	18	35	22.0	600	456.6	700.2
	12	B	1250	30	60	950	930	0.5	25	21	13.9	550	442.5	692.5
	13	B	1250	30	50	1010	930	0.5	40	15	7.2	350	—	678.0
	14	B	1250	30	40	1030	930	0.5	50	11	5.3	—	—	665.0
	15	C	1220	70	70	860	1020	1	5	163	132.3	650	485.5	714.5
	16	C	1220	70	55	895	1020	1	9	65	58.1	640	479.3	710.1
	17	C	1220	70	40	910	1020	1	14	35	31.3	640	467.8	704.6
	18	C	1220	50	60	930	1020	1	20	24	19.0	600	454.0	698.0
	19	C	1220	50	45	950	1020	1	27	17	12.5	550	437.9	690.3
	20	C	1220	40	55	1010	1020	1	35	13	8.7	400	—	681.5
	21	C	1220	40	45	1030	1020	1	45	10	6.1	—	—	670.5
	22	D	1150	70	70	845	880	15	8	99	68.5	650	481.6	711.8
	23	D	1150	70	50	860	880	15	12	52	38.8	640	472.4	706.9
	24	D	1150	50	65	910	880	15	20	34	19.0	540	454.0	698.0

Key:

Table 4

	Number	Steel	Heating Temperature (°C)	Degree of Piercing Work (%)	Degree of Finish rolling Work (%)	Finishing Temperature (°C	Heat Treatment Temperature (°C)
Examples of Present Invention							

[Table 4] (cont.)

	Heating Time and Time Kept in Furnace (min)	Thickness t (mm)	800-500°C Average Cooling Rate (°C/min)	K (°C/sec)	Tempering Temperature (°C)		
Examples of Present Invention							

K=10[illegible]/t[illegible]: (°C), L=500-2.3×t: (℃), M=720-1.1×t: (℃)

[0081]

[Table 5]

/9

表 5

	番号	鋼	加熱温度 (℃)	穿孔の加工度 (%)	仕上げ圧延加工度(%)	仕上がり温度 (℃)	加熱処理温度 (℃)	加熱在炉時間 (分)	肉厚 t (mm)	800-500℃平均冷却速度 (℃/秒)	K (℃/秒)	焼戻し温度 (℃)	L (℃)	M (℃)
本発明例	25	D	1150	50	40	900	880	15	27	28	12.5	600	437.9	690.3
	26	D	1150	40	50	950	880	15	35	14	8.7	550	–	681.5
	27	D	1150	40	45	970	880	15	45	12	6.1	–	–	670.5
	28	E	1100	80	70	880	880	30	9	82	58.1	650	479.3	710.1
	29	E	1100	60	55	910	880	30	14	45	31.3	640	467.8	704.6
	30	E	1100	80	60	930	880	30	20	28	19.0	640	454.0	698.0
	31	E	1100	40	55	950	880	30	31	14	10.3	580	–	685.9
	32	E	1100	40	40	970	880	30	40	11	7.2	–	–	676.0
	33	F	1250	70	60	880	950	5	7	117	82.6	650	483.9	712.3
	34	F	1250	50	75	940	950	5	20	35	19.0	640	454.0	698.0
	35	F	1250	40	55	1000	950	5	35	13	8.7	570	–	681.5
	36	F	1250	40	40	1030	950	5	48	13	5.6	–	–	667.2
	37	G	1220	70	70	870	920	10	5	198	132.3	650	488.6	714.5
	38	G	1220	50	70	920	920	10	18	46	22.0	640	459.6	700.2
	39	G	1220	40	60	950	920	10	30	23	10.8	600	–	687.0
	40	G	1220	40	40	990	920	10	46	12	6.1	–	–	670.5
	41	H	1250	70	65	880	900	15	8	80	68.5	650	481.6	711.2
	42	H	1250	50	70	940	900	15	18	38	22.0	640	459.6	700.2
	43	H	1250	40	55	990	900	15	36	22	8.3	500	–	680.4
	44	H	1250	40	40	1010	900	15	50	11	5.3	450	–	665.0
	45	I	1230	70	60	900	950	5	7	103	82.6	650	485.9	712.3
	46	I	1230	50	70	930	950	5	16	38	26.0	640	463.2	702.4
	47	I	1230	40	60	990	950	5	30	24	10.8	500	–	687.0
	48	I	1220	40	40	1030	950	5	45	13	6.1	–	–	670.5

Key:

Table 5

	Number	Steel	Heating Temperature (°C)	Degree of Piercing Work (%)	Degree of Finish rolling Work (%)	Finishing Temperature (°C)	Heat Treatment Temperature (°C)
Examples of Present Invention							

Table 5 (cont.)

	Heating Time and Time Kept in Furnace (min)	Thickness t (mm)	800-500°C Average Cooling Rate (°C/min)	K (°C/sec)	Tempering Temperature (°C)		
Examples of the Present Invention							

K=[illegible] (°C), L=[illegible], M=[illegible]

[0082]

[Table 6]

表6

	番号	鋼	加熱温度 (℃)	穿孔の加工度 (%)	仕上げ圧延加工度 (%)	仕上がり温度 (℃)	加熱処理温度 (℃)	加熱在炉時間 (分)	肉厚 t (mm)	800-500℃平均冷却速度 (℃/秒)	K (℃/秒)	焼戻し温度 (℃)	L (℃)	M (℃)
比較例	49	A	1250	60	*25	1000	950	20	25	14	13.9	550	442.5	692.5
	50	A	1250	60	40	*1100	950	30	24	18	14.7	600	444.8	698.6
	51	A	1250	60	40	1000	*1200	10	20	21	19.0	620	454.0	698.9
	52	A	1250	60	40	1000	1100	*60	25	15	13.9	600	442.5	692.5
	53	A	1250	60	70	860	960	15	7	56	62.8	*450	481.9	712.3
	54	A	1250	60	55	810	900	15	14	53	31.3	*—	487.8	704.6
	55	A	1250	60	40	930	900	15	22	20	16.6	*720	449.4	695.8
	56	A	1250	40	55	950	900	15	35	*5.2	6.7	700	—	681.5
	57	A	1250	40	40	970	900	15	48	*3.2	5.8	600	—	667.2
	58	*Q	1250	40	40	940	960	10	20	30	18.9	600	454.0	695.0
	59	*R	1250	40	40	940	960	10	24	31	14.7	600	444.8	693.6
	60	*S	1150	40	40	940	960	10	15	35	26.4	620	405.5	703.5
	61	*T	1250	40	40	940	960	10	18	25	22.0	550	458.8	700.2
	62	*U	1250	40	40	940	960	10	22	20	18.6	580	449.4	695.8
	63	*V	1250	40	40	940	960	10	20	24	18.0	640	454.0	698.0
	64	*W	1150	40	40	940	960	10	25	15	13.9	600	442.5	692.5

Key:

Table 6

	Number	Steel	Heating Temperature (°C)	Degree of Piercing Work (%)	Degree of Finish rolling Work (%)	Finishing Temperature (°C)	Heat Treatment Temperature (°C)
Comparative Examples							

Table 6 (cont.)

	Heating Time and Time Kept in Furnace (min)	Thickness t (mm)	800-500°C Average Cooling Rate (°C/min)	K (°C/sec)	Tempering Temperature (°C)		
Examples of Present Invention							

The numerical value with * shows that it is outside the range of the present invention.

- $K=10^{[illegible]}/t^{[illegible]}$ (°C/sec), $L=500-2.3\times t$ (°C), $M=720-1.1\times t$ (°C)

[0083] The tensile test was performed by so sampling tensile test pieces having a diameter of 4 mm at a gauge mark distance of 20 mm, and moreover, an impact test was performed by so sampling 10 mm wide, 5 mm thick 2 mm V-notched half-size Charpy test pieces that the center of the thickness in parallel to the direction of the pipe axis was the center of the thickness of the test piece. The break transition temperature vTrs of the yield strength and base material toughness shown in Tables 8 to 10 below is an average of both ends and the center of a pipe.

[0084] In the test on the weld cracking sensitivity of the weldability, a covered arc welding (heat input: 17 kJ/cm) was carried out on a diagonal Y-shaped weld cracking test piece at a preheating temperature of 50°C, based on JIS Z-3158, to examine the presence of cracking. In Tables 8 to 10 below, the test pieces in which no cracking was generated were denoted by a ○ and those in which cracking was generated were denoted by ×.

[0085] In the testing on the toughness of the welded parts, a multilayer welding was performed by gas metal arc welding (heat input: 23 kJ/cm) on the joints of the pipes subjected to groove work in which the butt-welded cross section formed a V shape, after which test pieces were so sampled that the weld joint bonds based on the cross-sectional microetched structure and the bottoms of the notches of the half-size impact test pieces were coincided to the HAZ position on the base material size 1 mm from the bonds. The evaluation in this impact test was performed from the break transition temperature vTrs (°C).

[0086] Table 7 is a table showing the yield strength values at the respective twenty-eight 28 positions on the seamless steel pipe performed at the rolling and heat treatment conditions shown in Table 3. Numbers P1 and P2 are examples wherein heating was performed just before the direction quenching based on the present invention, and moreover, numbers P3 and P4 are examples in which direct quenching

was done without performing a heat treatment after the rolling which corresponds to a conventional direct quenching.

[0087]

[Table 7]

表　7

番号	降伏強さ (kg/mm²)					標準偏差
	長手方向部位	幅方向部位				
		1	2	3	4	
P1	a	55.8	55.9	55.2	55.3	0.68
	b	55.9	54.9	54.5	54.6	
	c	55.7	55.8	55.5	55.4	
	d	55.8	56.3	57.3	56.5	
	e	56.0	56.5	56.8	56.9	
	f	56.7	56.6	55.9	58.2	
	g	55.3	56.2	55.7	55.6	
P2	a	54.9	54.3	56.0	54.6	0.75
	b	54.6	55.8	55.7	55.3	
	c	56.1	56.0	55.4	55.5	
	d	56.1	55.0	55.9	55.9	
	e	55.6	55.6	56.0	56.4	
	f	57.3	57.1	55.5	56.5	
	g	57.0	56.9	56.2	56.2	
P3	a	49.1	53.3	49.7	48.9	1.97
	b	50.9	52.5	52.0	50.4	
	c	52.6	53.6	51.1	50.4	
	d	52.8	55.5	50.8	53.9	
	e	56.3	52.2	51.9	55.9	
	f	55.1	55.5	54.3	54.7	
	g	50.3	53.3	52.5	48.7	
P4	a	49.2	51.3	50.9	48.2	2.09
	b	51.7	52.2	52.0	50.1	
	c	51.3	51.7	51.0	49.2	
	d	55.1	54.2	51.4	54.2	
	e	54.6	56.0	55.1	52.0	
	f	50.6	55.2	51.7	55.3	
	g	53.5	51.7	54.3	53.7	

Key:

Table 7

Reference Symbol	Yield Strength (kg/mm^2)					Standard Deviation
	Position in Longitudinal Direction	Position in Circumferential Direction				

[0088] Figures 2 to 5 are drawings showing the yield strength at each position of the seamless steel pipes P1 to P4. Numbers P1 and P2, which are examples of the present invention, are steel pipes having uniform performance with little dispersion in the longitudinal direction and also the circumferential direction. Vis-à-vis, simultaneous to the value of the yield strength itself being low in

both the longitudinal and circumferential directions, the dispersion of the steel pipes to which a conventional direct quenching was applied, such as numbers P3 and P4, is high. Numbers P1 to P4 all employed a steel A whose quenchability was suppressed by considering the weldability. But if no direct quenching following the heat treatment was performed after rolling on the steel having low quenchability as such, as in the method of the present invention, it is shown that high-strength, homogenous steel pipes are not obtained.

[0089] Tables 8 (numbers 1 to 24) and Table 9 (numbers 25 to 48) are tables showing the test results for steel pipes to which the method of the present invention shown in Tables 4 and 5, respectively, was applied.

[0090] These results show that substantially the same yield strength is obtained as long as steel is obtained by setting the tempering temperature within the range of the present invention. The toughness of the base material, the weld cracking sensitivity, and the toughness of the welded part also are outstanding.

[0091]

[Table 8]

表 8

	番号	鋼	降伏強さ (kgf/mm²)	母材靱性 vTrs (℃)	斜め拘束割れ試験結果	溶接継手部ボンドの靱性 vTrs (℃)	HAZ 1mm 靱性 vTrs (℃)
本発明例	1	A	55.5	-83	○	-66	-74
	2	A	57.4	-76	○	-58	-62
	3	A	56.7	-63	○	-44	-55
	4	A	57.5	-73	○	-49	-57
	5	A	56.5	-92	○	-66	-71
	6	A	57.1	-64	○	-39	-54
	7	A	56.4	-57	○	-38	-41
	8	B	61.4	-72	○	-56	-66
	9	B	62.2	-81	○	-63	-65
	10	B	61.7	-69	○	-51	-58
	11	B	61.7	-91	○	-64	-68
	12	B	62.6	-72	○	-55	-62
	13	B	63.5	-54	○	-41	-56
	14	B	63.4	-70	○	-58	-68
	15	C	55.5	-81	○	-63	-69
	16	C	55.9	-78	○	-61	-63
	17	C	56.8	-78	○	-60	-68
	18	C	55.6	-67	○	-44	-57
	19	C	56.4	-77	○	-54	-67
	20	C	57.9	-80	○	-42	-49
	21	C	57.6	-66	○	-39	-44
	22	D	65.1	-86	○	-45	-55
	23	D	66.2	-89	○	-45	-58
	24	D	67.4	-57	○	-41	-44

Key:

Table 8

	Number	Steel	Yield Strength (kgf/mm^2)	Base Material Toughness vTrs (°C)	Diagonal Restriction Cracking Test Results	Welded Joint Bond Toughness vTrs (°C)	HAZ 1 mm Toughness vTrs (°C)
Examples of Present Invention							

[0092]

[Table 9]

表 9

	番号	鋼	降伏強さ (kgf/mm²)	母材靭性 vTrs (℃)	斜め拘束割れ試験結果	溶接継手部ボンドの靭性 vTrs (℃)	HAZ 1mm 靭性 vTrs (℃)
本発明例	25	D	65.3	-69	○	-47	-53
	26	D	67.6	-69	○	-49	-55
	27	D	67.5	-65	○	-47	-53
	28	E	56.6	-77	○	-56	-66
	29	E	57.8	-82	○	-64	-65
	30	E	58.8	-83	○	-61	-68
	31	E	57.5	-70	○	-62	-66
	32	E	56.4	-75	○	-55	-63
	33	F	48.8	-75	○	-52	-67
	34	F	49.3	-80	○	-60	-70
	35	F	48.6	-66	○	-43	-61
	36	F	47.8	-64	○	-42	-64
	37	G	50.9	-74	○	-55	-56
	38	G	50.6	-84	○	-61	-68
	39	G	50.4	-62	○	-43	-54
	40	G	50.1	-61	○	-42	-44
	41	H	70.8	-76	○	-63	-62
	42	H	71.7	-71	○	-48	-58
	43	H	70.5	-84	○	-45	-48
	44	H	71.7	-56	○	-35	-39
	45	I	59.4	-71	○	-47	-57
	46	I	58.7	-87	○	-65	-78
	47	I	58.3	-66	○	-46	-54
	48	I	59.5	-57	○	-39	-42

Key:

Table 9

	Number	Steel	Yield Strength (kgf/mm^2)	Base Material Toughness vTrs (°C)	Diagonal Restriction Cracking Test Results	Welded Joint Bond Toughness vTrs (°C)	HAZ 1 mm Toughness vTrs (°C)
Examples of Present Invention							

[0093] Table 10 (numbers 49 to 64) is a table showing the test results for pipes manufactured at conditions outside the range of the present invention shown in Table 6. In this drawing, the chemical composition of the steel of numbers 49 to 57 fall within the range of the present invention, but the steel was manufactured in the method of manufacture at conditions outside the range of the present invention.

[0094] The finishing temperature after the finish rolling work, the heat treatment temperature, and the heating time and time kept in the furnace of numbers 49 to 52 thereof are all outside the range of the present invention. As a result, the toughness is inferior. In addition, numbers 53 to 57 are cases in which the thickness was changed systematically. But since the average cooling rate of the direct quenching and the tempering temperature are outside the range of the present invention, the strength varies greatly in accordance with the variation in the thickness, while the toughness and weldability both are inferior.

[0095] Since the steel chemical composition of numbers 58 to 64 are outside the range of the present invention, the toughness of the welded parts is especially low and the weld cracking sensitivity is also high.

[0096]

[Table 10]

表 10

	番号	鋼	降伏強さ (kgf/mm²)	母材靭性 vTrs (℃)	斜め拘束割れ試験結果	溶接継手部ボンドの靭性 vTrs (℃)	HAZ 1mm 靭性 vTrs (℃)
比較例	49	A	54.3	-34	○	-16	-20
	50	A	54.8	-28	○	+3	-11
	51	A	57.6	-10	○	+5	-3
	52	A	55.2	-26	○	-7	-16
	53	A	72.8	-38	×	-18	-29
	54	A	68.1	-35	×	-29	-29
	55	A	45.7	-41	○	-25	-27
	56	A	44.3	-42	○	-23	-32
	57	A	41.2	-37	○	-21	-22
	58	Q	72.0	-30	×	-15	-27
	59	R	76.5	-27	×	-5	-14
	60	S	85.6	-2	×	14	18
	61	T	90.7	-8	×	12	9
	62	U	67.4	-55	×	-24	-27
	63	V	70.2	-30	×	-19	-28
	64	W	85.1	-10	×	10	8

Key:

Table 10

	Number	Steel	Yield Strength (kgf/mm^2)	Base Material Toughness vTrs (°C)	Diagonal Restriction Cracking Test Results	Welded Joint Bond Toughness vTrs (°C)	HAZ 1 mm Toughness vTrs (°C)
Comparative Examples							

[0097]

[Advantages of the Invention] According to the method of the present invention, a seamless steel pipe having outstanding weldability, high strength and high toughness can be manufactured stably at a high productivity, and further, it can be manufactured in a wide thickness range from the same steel; hence, the amount of stock billets can be reduced, thus bringing about extremely preferable advantages in industrial developments in this field.

[Brief Explanation of the Drawings]

[Figure 1] Figure 1 is a drawing showing the influence of the tempering temperature on the yield strength of seamless steel pipes having various thicknesses manufactured in the method of the present invention.

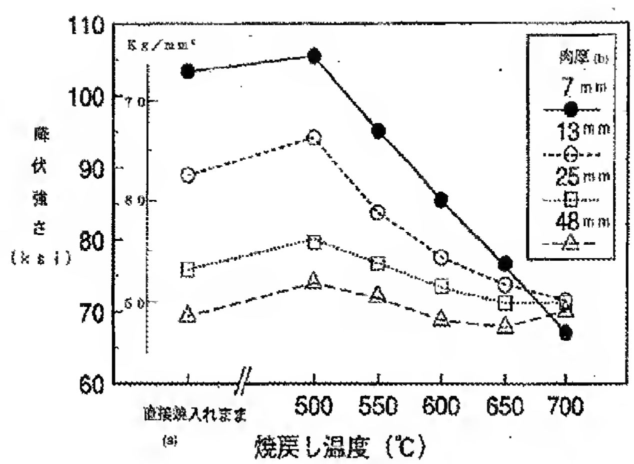
[Figure 2] Figure 2 is a drawing showing the yield strength at each position of the seamless steel pipe P1 in Table 3.

[Figure 3] Figure 3 is a drawing showing the yield strength at each position of the seamless steel pipe P2 in Table 3.

[Figure 4] Figure 4 is a drawing showing the yield strength at each position of the seamless steel pipe P3 in Table 3.

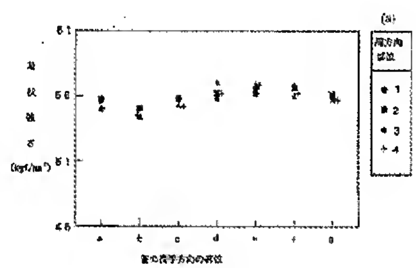
[Figure 5] Figure 5 is a drawing showing the yield strength at each position of the seamless steel pipe P4 in Table 3.

[Figure 1]



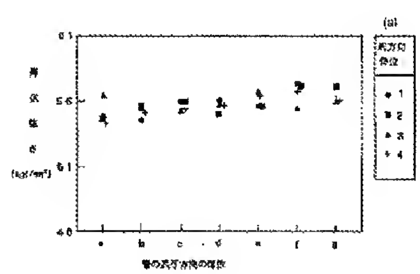
Key: X-axis) Tempering Temperature (°C); Y-axis) Yield Strength (ksi); a) direct quenched as is; b) thickness

[Figure 2]



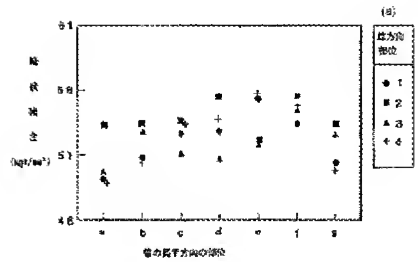
Key: X-axis) Position in Longitudinal Direction of Pipe; Y-axis) Yield Strength (kgf/mm^2); a) Position in circumferential direction

[Figure 3]



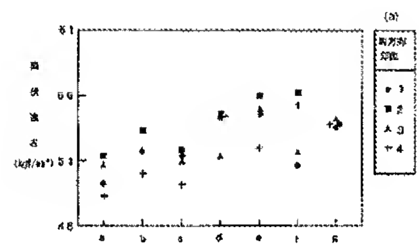
Key: X-axis) Position in Longitudinal Direction of Pipe; Y-axis) Yield Strength (kgf/mm^2); a) Position in circumferential direction

[Figure 4]



Key: X-axis) Position in Longitudinal Direction of Pipe; Y-axis) Yield Strength (kgf/mm^2); a) Position in circumferential direction

[Figure 5]



Key: X-axis) Position in Longitudinal Direction of Pipe; Y-axis) Yield Strength (kgf/mm^2); a) Position in circumferential direction